

Vegetable root surface area after 8 weeks of growth

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<https://sites.google.com/view/low-tech-farm-tools>

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Introduction:

Crops with early rapid root growth are better able to established and compete for soil water and plant nutrients. These crops are suited for dry farming because without irrigation; their roots must grow faster than the surface soil drying front. Crops with slower root growth require more water management and are less suited for dry farming.

Early root growth rate of vegetable and field crops were assessed by calculating root surface area after 8 weeks of growth. Drawing of crop roots were obtained from Root Development of Vegetable Crops by Weaver and Bruner (1927); and Root Development of Field Crops (1926) by JE Weaver. The grayscale root drawings were converted into binary black and white images, the number of black pixels in the binary images were counted and converted to root surface area to construct a list of crops in increasing order of early root growth rate.

Summary:

Development of Vegetable Crops by Weaver and Bruner; and Root Development of Field Crops by Weaver provided 11 drawings of root crops at 8 weeks of growth. Their computed surface area listed in increasing order of is as follows:

Onion < parsley < parsnip < cabbage < bean < potato < cauliflower < sweet potato < tomato < field corn < sweet corn

There were 5 other crops with root drawings older than 8 weeks of growth. These crop root surface areas were calculated and extrapolated back to the 8 weeks of growth, assuming logarithmic growth rate. When these crops were added to the list of crop root surface area at 8 weeks of growth, the increasing order of growth rate is as follows; older crops extrapolate back to 8 weeks in parenthesis:

Onion < (leek) < parsley < parsnip < (radish) < (spinach) < (lettuce) < (kohlrabi) < cabbage < bean < potato < cauliflower < sweet potato < tomato < field corn < sweet corn

There were 12 crops with root drawings younger than 8 weeks of growth. Their root surface area was extrapolated forward to 8 weeks of growth, assuming logarithmic growth rate. However, small errors are magnified when extrapolating logarithmic growth forward. Alternatively, the assumption of logarithmic growth rate is incorrect at that stage of root development. This requires 'best guess' judgement for these data. By adding these younger crops to the list, the increasing order of crop root surface area at 8 weeks of growth rate, is as follows:

(carrot = leek = onion = parsley = parsnip = radish) <
(beet = eggplant = lettuce = spinach) <
(bean = cabbage = kohlrabi) <
(cauliflower = pea = potato) <
(chard = cucumber = field corn = muskmelon = okra = pepper = potato = rutabaga = squash = sweet corn = sweet potato = tomato = turnip)

Lots of assumptions made in constructing this list. Unaccounted factors include planting date, crop variety, weather, soil characteristics etc. The computed root surface area does not

account for technical issues such as accuracy of root drawings, the transfer of root drawings to book and book to digital format, removal of grid lines from drawings without affecting root surface area measurements and effectiveness of software algorithm in converting grayscale to binary.

Method:

Grayscale root drawing of young crops were copied from Root Development of Vegetable Crops by Weaver and Bruner (1927) and Root Development of Field Crops (1926) by JE Weaver. Crops were grouped by age, in weeks +/- 3 days. The group with the largest number of crops was the 8-week group, followed by 6-week group. Root surface area of crops older than 8 weeks were extrapolated backward to 8 weeks by assuming exponential root growth rate between a younger than 8-week and an older than 8-week drawing. If there is only older drawing, then the 'younger' data point is 0,0 no roots at planting. However, extrapolating root area of younger crops forward to 8 weeks was subject to small errors that magnifies exponentially resulting in some unusable data and the assumption of exponential growth is not valid.

Method for computing root surface area from grayscale drawings is as follows:

1. Make 2 copies of the root drawings
 - a. Use one copy to measure the number of pixels per square foot; the grid lines are 1 ft apart on the x and y axis.
 - b. On the second copy, erase the grid lines; otherwise the grid lines would be counted as root
2. Using the root drawings without grid lines, convert the grayscale image to binary. Softwares used were: '[ImageJ](#)' (from National Institute of Health), '[Image Magick](#)' and '[Adobe Photoshop](#)'. 'ImageJ' and 'Image Magick' have default cut-off threshold for converting grayscale pixel to either black or white. Adobe Photoshop and ImageJ allow users to select cut-off threshold. A threshold value of 178 converts 11/16th of the shades of grey as black; threshold value of 195 converts 3/4th of the shades of grey as black.
 - a. To convert with ImageJ > open file > process > binary > make binary. Count the number of black pixels with ImageJ > analyze > histogram > list > value 255 = black, because of an inverted look-up-table; record the 'count'.
 - b. To convert with Photoshop > open file > image > adjustment > threshold > adjust to 178 or 195 > ok. Count the number of black pixels with Photoshop > image > histogram > select level = 0 and record the 'count'.
 - c. To convert with Image Magick requires 'terminal' input in Linux using the command 'convert -monochrome in.jpg out.jpg'
3. Check the binary images and erase stray marking and dithering speckles if present, then reconvert the image to binary and recount the number of black pixels.
4. Calculate root surface area: divide [number of black pixels (root)] by [number of pixels/sq ft in the image] = area of roots, sq ft.
5. Projection of root area assuming exponential growth:
 - a. Multiply the computed root area by 100 to avoid log values less than 1. This facilitates plotting of data on a graph for visual inspection and using (0,0) at planting date with zero root growth; log values greater than zero and less than 1 is negative; log of zero is minus infinity.
 - b. Find the slope of the growth rate using 2 different growth dates: $[(\ln(100 * \text{root area at date2}) - \ln(100 * \text{root area at date1})) / ((\text{root age at date2} - \text{root age at date1}))] = \ln 100 \text{ growth rate per day}$
 - c. Project the root area for 56 days (8 weeks): $\ln(100 * \text{root area at date1}) + \text{slope} * (56 \text{ days} - \text{days at date1}) = \ln 100 \text{ root area at 8 weeks}$
 - d. Convert ln root area back to sq ft: $[\text{Exp}(\ln \text{ root area})] / 100$ to cancel the 100 multiplication factor.

6. All 3 softwares for converting grayscale image to binary image yielded the same sequence of root surface area in crops, although the number of black pixels may differ.

Results:

The computed crop root surface area, in square foot, is listed in increasing order and grouped by similar root surface area using ImageJ data.

Crop	Age used for extrapolation	Root surface area at 56 days, sq ft
onion	55	0.06
leek	64	0.08
parsley	57	0.09
carrot	47	0.14
parsnip	81	0.18
radish	62	0.31
beet	68	0.82
spinach	68	0.86
lettuce	62	0.89
eggplant	52	0.92
kohlrabi	64	1.41
bean	57	1.5
cabbage	75	1.54
cauliflower transplant	57	2.01
potato half root x 2	56	2.01
pea	43	2.36
sweet potato transplant	55	3.14
tomato transplant	56	3.39
chard	49	3.79
squash	41	4.38
field corn	57	4.69
sweet corn	55	5.82
rutabaga	41	6.88
cucumber	41	11.78
turnip	41	10.36
muskmelon	35	25.41
pepper transplant	39	89.43
pumpkin	20	306.98
okra half root x 2	23	631.73

Highlighted in yellow are root surface areas extrapolation of younger crops to 56 days of growth, with magnification error; younger crops were not growing at exponential rate. Highlight in green are transplanted crops.

Combining crops with 8 weeks of growth (56 days +/- 3) and older crops extrapolated to 8 weeks of growth, the increasing order of root surface area is as follows; older crops in parenthesis:

Onion < (leek) < parsley < parsnip < (radish) < (spinach) < (lettuce) < (kohlrabi) < cabbage < bean < potato < cauliflower < sweet potato < tomato < field corn < sweet corn.

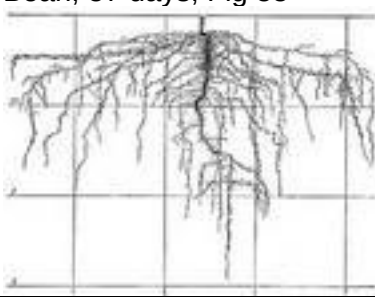
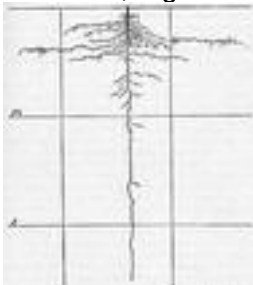
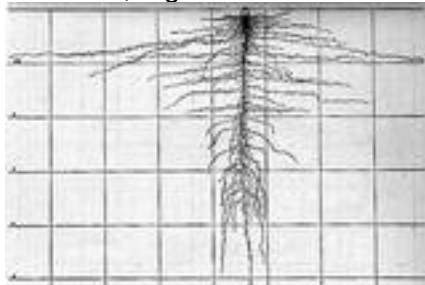
The crop list of increasing order root surface area was expanded by adding 12 crops with younger than 8 weeks of growth. Younger crop root surface area was extrapolated forward to 56 days assuming exponential root growth rate. Adjusting for magnification error of forward extrapolation, and grouped into similar root surface area, along with best guess, the order is as follows (crops highlight in green were transplanted):

[carrot = leek = onion = parsley = parsnip = radish = (0.06-0.31 sq ft root area)] <
 [beet = eggplant = lettuce = spinach = (0.82-0.92 sq ft)] <
 [bean = cabbage = kohlrabi = (1.4-1.5 sq ft)] <
 [cauliflower = pea = potato = (2.01-2.4 sq ft)] <
 [chard = cucumber = field corn = muskmelon = okra = pepper = (potato) = rutabaga = squash = sweet corn = sweet potato = tomato = turnip = (3-6? sq ft)]

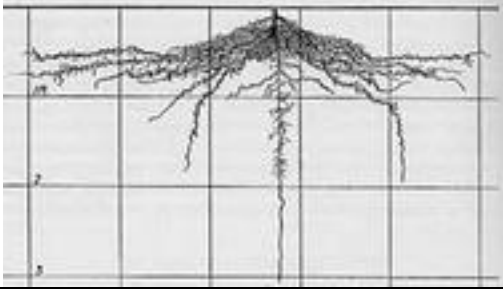
Potato is listed twice, once as calculate surface area of 2.01 sq ft after 56 days of growth. Potato is also placed in the higher surface area group because the drawing shows thicker diameter root; a 2-dimensional surface area underestimates 3-dimensional root volume.

Root drawing used in the calculation:

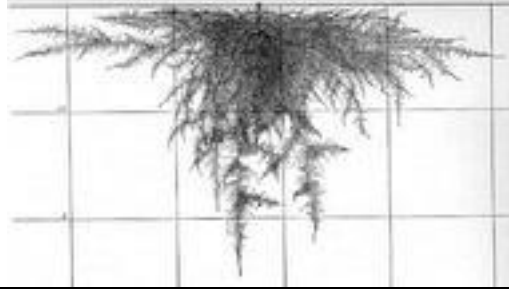
Crop drawings are in alphabetical order with age of root (days) grown from seed unless specified as transplant; and figure number is the number used in the book. For okra and potato, only half of the root system was drawn due to root density. For complete set of root drawing, see original.

Bean, 57 days, Fig 55 	This area left blank
Beet 42d, Fig 19 	Beet 68d, Fig 20 

Cabbage 55d, Fig 28



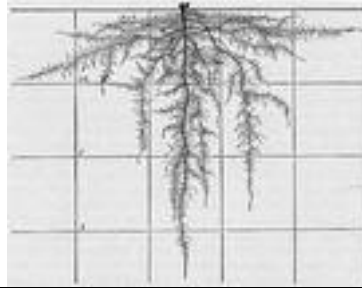
Cauliflower 57d, transplant, Fig 36



Chard 25d, Fig 23



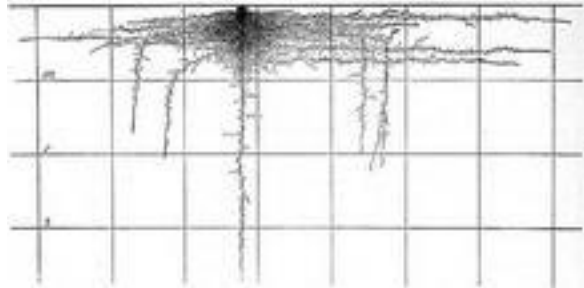
Chard 49d, Fig 24



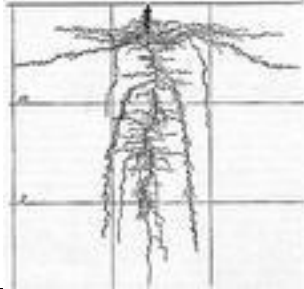
Cucumber 27d, Fig 81



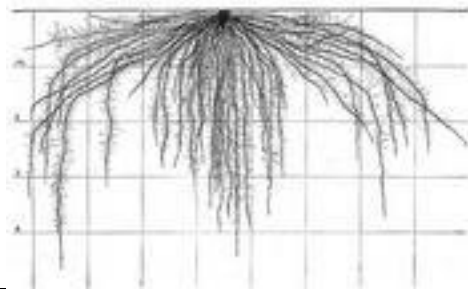
Cucumber 41d, Fig 82



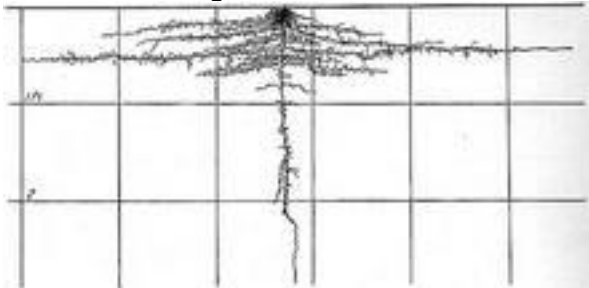
Eggplant 52d, Fig 77



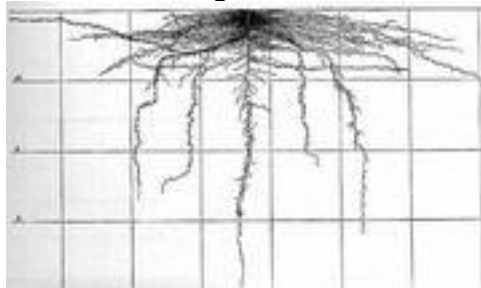
Field corn 57d



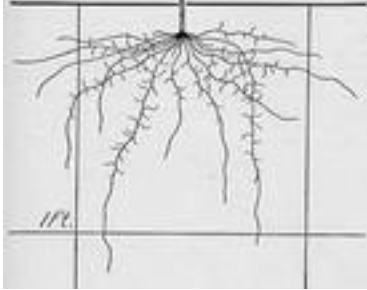
Kohlrabi 44d, Fig 38



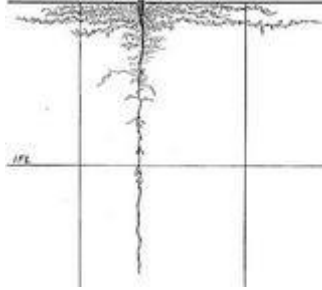
Kohlrabi 64d, Fig 39



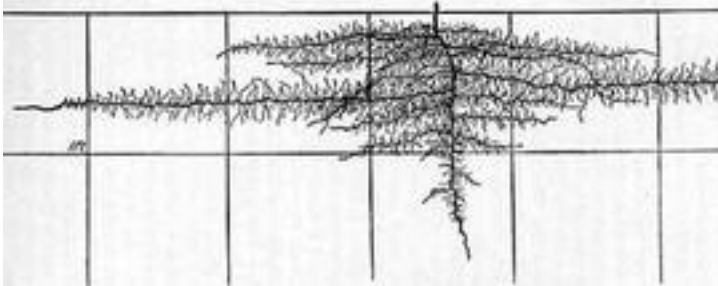
Leek 64d, Fig 11



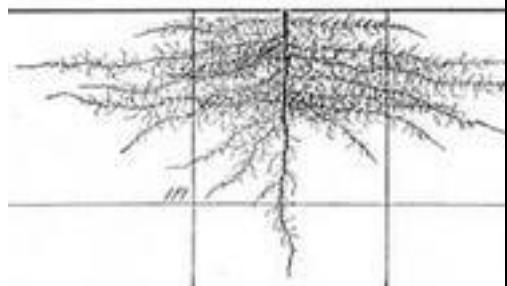
Lettuce 38d, Fig 91



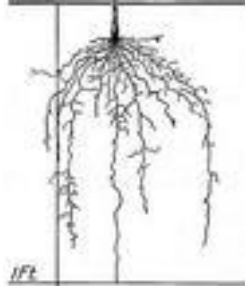
Muskmelon 35d, Fig 84



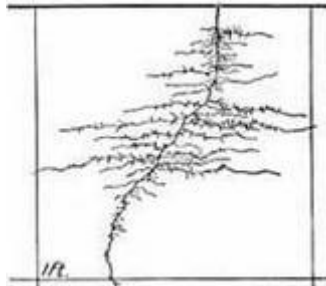
Okra 23d, half root system, Fig 59



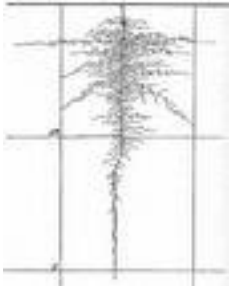
Onion 55d, Fig 7



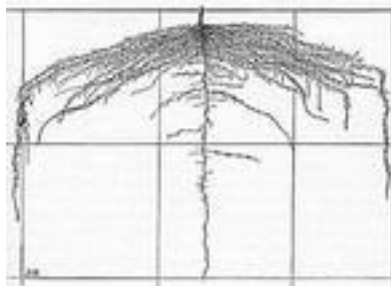
Parsley 57d, Fig 64



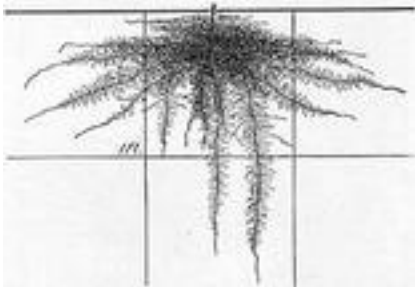
Parsnip 55d, Fig 65



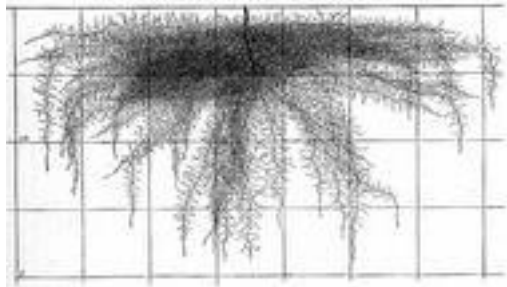
Peas 43d, Fig 51



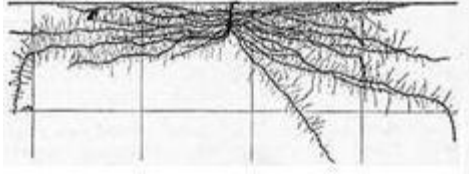
Pepper 24 d transplant, Fig 78



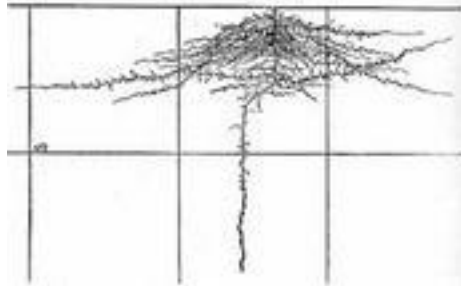
Pepper 39d, transplant, Fig 79



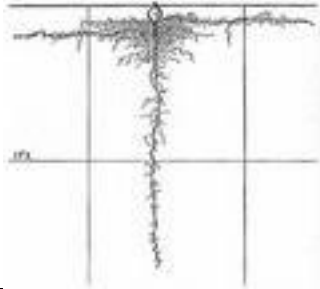
Potato 56d, half root system



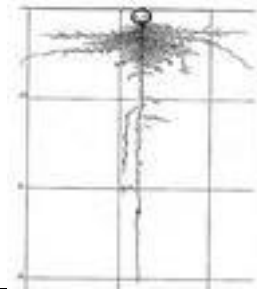
Pumpkin 20d, Fig 90



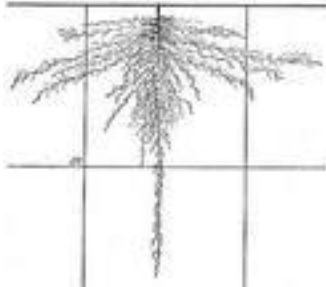
Radish 38d, Fig46



Radish 62d Fig47



Rutabaga 24d, Fig 43



Rutabaga 41d, Fig 44



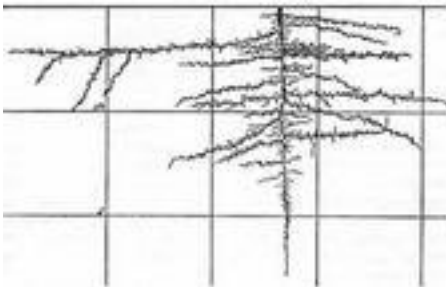
Spinach 43d, Fig 26



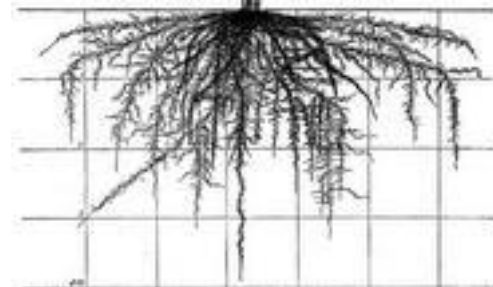
Spinach 68d, Fig 27



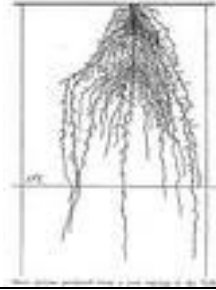
Squash 41d, Fig 87



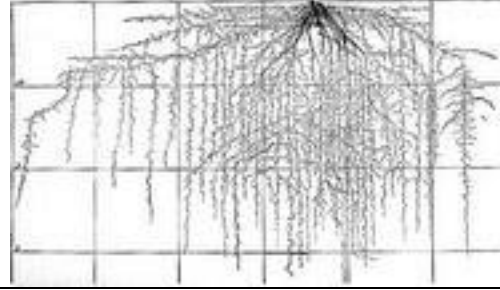
Sweet corn 55d, Fig4



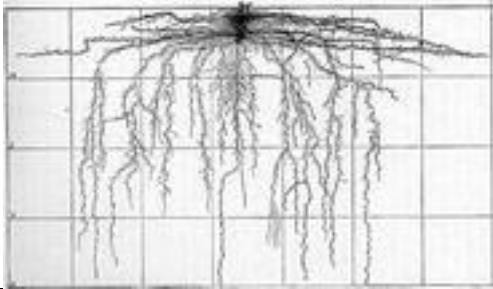
Sweet potato 23d, transplant, Fig 68



Sweet potato 55d, transplant, Fig 69



Tomato 56d, transplant, Fig 73



Turnip 24d Fig41

